OLIGONUCLEOTIDE MODULATION OF CELL ADHESION

INTRODUCTION

This application is a continuation-in-part of application Serial No 09/659,288, filed September 12, 2000, which is a continuation of application Serial No. 09/128,496, filed August 3, 1998 (U.S. Patent No. 6,169,079), which is a continuation of application Serial No. 08/440,740, filed May 12, 1995 (U.S., Patent No. 5,843,738), which is a continuation-in-part of application Serial No. 08/063,167 filed May 17, 1993 (U.S. Patent No. 5,514,788), which is a continuation of application Serial No. 07/969,151 filed February 10, 1993 (abandoned), which is a continuation-in-part of application Serial No. 08/007,997 filed January 21, 1993 (U.S. Patent 5,591,623). The entire contents of these applications and patents is incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates to diagnostics, research reagents and therapies for disease states which respond to modulation of the synthesis or metabolism of cell adhesion molecules. In particular, this invention relates to antisense oligonucleotide interactions with certain messenger ribonucleic acids (mRNAs) or DNAs involved in the synthesis of proteins that regulate adhesion of white blood cells to other white blood cells and to other cell types. Antisense oligonucleotides designed to hybridize to the mRNA encoding intercellular adhesion molecule-1 (ICAM-1), endothelial leukocyte adhesion molecule-1 (ELAM-1, also known as E-selectin), and vascular cell adhesion molecule-1

(VCAM-1) are provided. These oligonucleotides have been found to lead to the modulation of the activity of the RNA or DNA, and thus to the modulation of the synthesis and metabolism of specific cell adhesion molecules. Palliation and therapeutic effect result.

BACKGROUND OF THE INVENTION

Inflammation is a localized protective response elicited by tissues in response to injury, infection, or tissue destruction resulting in the destruction of the infectious or injurious agent and isolation of the injured tissue. A typical inflammatory response proceeds as follows: recognition of an antigen as foreign or recognition of tissue damage, synthesis and release of soluble inflammatory mediators, recruitment of inflammatory cells to the site of infection or tissue damage, destruction and removal of the invading organism or damaged tissue, and deactivation of the system once the invading organism or damage has been resolved. In many human diseases with an inflammatory component, the normal, homeostatic mechanisms which attenuate the inflammatory responses are defective, resulting in damage and destruction of normal tissue.

Cell-cell interactions are involved in the activation of the immune response at each of the stages described above. One of the earliest detectable events in a normal inflammatory response is adhesion of leukocytes to the vascular endothelium, followed by migration of leukocytes out of the vasculature to the site of infection or injury. The adhesion of these leukocytes, or white blood cells, to vascular endothelium is an obligate step in the migration out of the vasculature. Harlan, J.M., *Blood* **1985**, 65, 513-525. In general, the first inflammatory cells to appear at the site of inflammation are neutrophils followed by monocytes, and lymphocytes. Cell-cell interactions are also

critical for propagation of both B-lymphocytes and T-lymphocytes resulting in enhanced humoral and cellular immune responses, respectively.

The adhesion of white blood cells to vascular endothelium and other cell types is mediated by interactions between specific proteins, termed "adhesion molecules," located on the plasma membrane of both white blood cells and vascular endothelium. The interaction between adhesion molecules is similar to classical receptor ligand interactions with the exception that the ligand is fixed to the surface of a cell instead of being soluble. The identification of patients with a genetic defect in leukocyte adhesion has enabled investigators to identify a family of proteins responsible for adherence of white blood cells. Leukocyte adhesion deficiency (LAD) is a rare autosomal trait characterized by recurrent bacterial infections and impaired pus formation and wound healing. The defect was shown to occur in the common B-subunit of three heterodimeric glycoproteins, Mac-1, LFA-1, and p150,95, normally expressed on the outer cell membrane of white blood cells. Anderson and Springer, *Ann. Rev. Med.* **1987**, 38, 175-194. Patients suffering from LAD exhibit a defect in a wide spectrum of adherence-dependent functions of granulocytes, monocytes, and lymphocytes. Three ligands for LFA-1 have been identified, intercellular adhesion molecules 1, 2 and 3 (ICAM-1, ICAM-2 and ICAM-3). Both Mac-1 and p150,95 bind complement fragment C3bi and perhaps other unidentified ligands. Mac-1 also binds ICAM-1.

Other adhesion molecules have been identified which are involved in the adherence of white blood cells to vascular endothelium and subsequent migration out of the vasculature. These include endothelial leukocyte adhesion molecule-1 (ELAM-1), vascular cell adhesion molecule-1 (VCAM-1) and granule membrane protein-140 (GMP-140) and their respective

receptors. The adherence of white blood cells to vascular endothelium appears to be mediated in part if not *in toto* by the five cell adhesion molecules ICAM-1, ICAM-2, ELAM-1, VCAM-1 and GMP-140. Dustin and Springer, *J. Cell Biol.* **1987**, 107, 321-331. Expression on the cell surface of ICAM-1, ELAM-1, VCAM-1 and GMP-140 adhesion molecules is induced by inflammatory stimuli. In contrast, expression of ICAM-2 appears to be constitutive and not sensitive to induction by cytokines. In general, GMP-140 is induced by autocoids such as histamine, leukotriene B_4, platelet activating factor, and thrombin. Maximal expression on endothelial cells is observed 30 minutes to 1 hour after stimulation, and returns to baseline within 2 to 3 hours. The expression of ELAM-1 and VCAM-1 on endothelial cells is induced by cytokines such as interleukin-1ß and tumor necrosis factor, but not gamma-interferon. Maximal expression of ELAM-1 on the surface of endothelial cells occurs 4 to 6 hours after stimulation, and returns to baseline by 16 hours. ELAM-1 expression is dependent on new mRNA and protein synthesis. Elevated VCAM-1 expression is detectable 2 hours following treatment with tumor necrosis factor, is maximal 8 hours following stimulation, and remains elevated for at least 48 hours following stimulation. Rice and Bevilacqua, *Science* **1989**, 246, 1303-1306. ICAM-1 expression on endothelial cells is induced by cytokines interleukin-1 tumor necrosis factor and gamma-interferon. Maximal expression of ICAM-1 follows that of ELAM-1 occurring 8 to 10 hours after stimulation and remains elevated for at least 48 hours.

GMP-140 and ELAM-1 are primarily involved in the adhesion of neutrophils to vascular endothelial cells. VCAM-1 primarily binds T and B lymphocytes. In addition, VCAM-1 may play a role in the metastasis of melanoma, and possibly other cancers. ICAM-1 plays a role in adhesion of neutrophils to vascular endothelium, as well as adhesion of

monocytes and lymphocytes to vascular endothelium, tissue fibroblasts and epidermal keratinocytes. ICAM-1 also plays a role in T-cell recognition of antigen presenting cell, lysis of target cells by natural killer cells, lymphocyte activation and proliferation, and maturation of T cells in the thymus. In addition, recent data have demonstrated that ICAM-1 is the cellular receptor for the major serotype of rhinovirus, which account for greater than 50% of common colds. Staunton et al., *Cell* **1989**, 56, 849-853; Greve et al., *Cell* **1989**, 56, 839-847.

Expression of ICAM-1 has been associated with a variety of inflammatory skin disorders such as allergic contact dermatitis, fixed drug eruption, lichen planus, and psoriasis; Ho et al., *J. Am. Acad. Dermatol.* **1990**, 22, 64-68; Griffiths and Nickoloff, *Am. J. Pathology* **1989**, 135, 1045-1053; Lisby et al., *Br. J. Dermatol.* **1989**,120, 479-484; Shiohara et al., *Arch. Dermatol.* **1989**, 125, 1371-1376. In addition, ICAM-1 expression has been detected in the synovium of patients with rheumatoid arthritis; Hale et al., *Arth. Rheum.* **1989**, 32, 22-30, pancreatic B-cells in diabetes; Campbell et al., *Proc. Natl. Acad. Sci. U.S.A.* **1989**, 86, 4282-4286; thyroid follicular cells in patients with Graves' disease; Weetman et al., *J. Endocrinol.* **1989**, 122, 185-191; and with renal and liver allograft rejection; Faull and Russ, *Transplantation* **1989**, 48, 226-230; Adams et al., *Lancet* **1989**, 1122-1125. ICAM-1 is also expressed on corneal endothelial cells and is induced on corneal endothelial cells in response to inflammatory stimuli.

It is has been hoped that inhibitors of ICAM-1, VCAM-1 and ELAM-1 expression would provide a novel therapeutic class of anti-inflammatory agents with activity towards a variety of inflammatory diseases or diseases with an inflammatory component such as asthma, rheumatoid arthritis, allograft rejections, inflammatory bowel disease, various

dermatological conditions, and psoriasis. In addition, inhibitors of ICAM-1, VCAM-1, and ELAM-1 may also be effective in the treatment of colds due to rhinovirus infection, AIDS, Kaposi's sarcoma and some cancers and their metastasis. To date, there are no known therapeutic agents which effectively prevent the expression of the cellular adhesion molecules ELAM-1, VCAM-1 and ICAM-1. The use of neutralizing monoclonal antibodies against ICAM-1 in animal models provide evidence that such inhibitors if identified would have therapeutic benefit for asthma; Wegner et al., *Science* **1990**, 247, 456-459, renal allografts; Cosimi et al., *J. Immunol.* **1990**, 144, 4604-4612, and cardiac allografts; Isobe et al., *Science* **1992**, 255, 1125-1127. The use of a soluble form of ICAM-1 molecule was also effective in preventing rhinovirus infection of cells in culture. Marlin et al., *Nature* **1990**, 344, 70-72.

Current agents which affect intercellular adhesion molecules include synthetic peptides, monoclonal antibodies, and soluble forms of the adhesion molecules. To date, synthetic peptides which block the interactions with VCAM-1 or ELAM-1 have not been identified. Monoclonal antibodies may prove to be useful for the treatment of acute inflammatory response due to expression of ICAM-1, VCAM-1 and ELAM-1. However, with chronic treatment, the host animal develops antibodies against the monoclonal antibodies thereby limiting their usefulness. In addition, monoclonal antibodies are large proteins which may have difficulty in gaining access to the inflammatory site. Soluble forms of the cell adhesion molecules suffer from many of the same limitations as monoclonal antibodies in addition to the expense of their production and their low binding affinity. Thus, there is a long felt need for molecules which effectively inhibit intercellular adhesion molecules. Antisense oligonucleotides avoid many of the pitfalls of

current agents used to block the effects of ICAM-1, VCAM-1 and ELAM-1.

PCT/US90/02357 (Hession et al.) discloses DNA sequences encoding Endothelial Adhesion Molecules (ELAMs), including ELAM-1 and VCAM-1 and VCAM-1b. A number of uses for these DNA sequences are provided, including (1) production of monoclonal antibody preparations that are reactive for these molecules which may be used as therapeutic agents to inhibit leukocyte binding to endothelial cells; (2) production of ELAM peptides to bind to the ELAM ligand on leukocytes which, in turn, may bind to ELAM on endothelial cells, inhibiting leukocyte binding to endothelial cells; (3) use of molecules binding to ELAMS (such as anti-ELAM antibodies, or markers such as the ligand or fragments of it) to detect inflammation; (4) use of ELAM and ELAM ligand DNA sequences to produce nucleic acid molecules that intervene in ELAM or ELAM ligand expression at the translational level using antisense nucleic acid and ribozymes to block translation of a specific MRNA either by masking MRNA with antisense nucleic acid or cleaving it with a ribozyme. It is disclosed that coding regions are the targets of choice. For VCAM-1, AUG is believed to be most likely; a 15-mer hybridizing to the AUG site is specifically disclosed in Example 17.

In the United States, 40,000 corneal transplants are performed per year. Human corneal allograft rejection is a major problem in corneal clinical practice. To date, no totally reliable and reproducible medication regimen provides assurance that allograft rejection will not occur in high risk patients, including those with corneal neovascularization and previous rejections. Corneal transplants require months of meticulous follow-up care, and significantly restrict the physical activity of recipients. In addition, corneal transplantation often necessitates

general anesthesia and is very expensive. Therefore, allograft rejection presents significant personal, economic and anesthetic risks to patients. Thus, there is a need for compositions and methods which will prevent corneal allograft rejection.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is the mRNA sequence of human intercellular adhesion molecule-1 (ICAM-1).

FIGURE 2 is the mRNA sequence of human endothelial leukocyte adhesion molecule-1 (ELAM-1).

FIGURE 3 is the mRNA sequence of human vascular cell adhesion molecule-1 (VCAM-1).

FIGURE 4 is a graphical representation of the induction of ICAM-1 expression on the cell surface of various human cell lines by interleukin-1 and tumor necrosis factor.

FIGURE 5 is a graphical representation of the effects of selected antisense oligonucleotides on ICAM-1 expression on human umbilical vein endothelial cells.

FIGURE 6A and 6B are a graphical representation of the effects of an antisense oligonucleotide on the expression of ICAM-1 in human umbilical vein endothelial cells stimulated with tumor necrosis factor and interleukin-1.

FIGURE 7 is a graphical representation of the effect of antisense oligonucleotides on ICAM-1 mediated adhesion of DMSO differentiated HL-60 cells to control and tumor necrosis factor treated human umbilical vein endothelial cells.

FIGURE 8 is a graphical representation of the effects of selected antisense oligonucleotides on ICAM-1 expression in A549 human lung carcinoma cells.

FIGURE 9 is a graphical representation of the effects of selected antisense oligonucleotides on ICAM-1 expression in primary human keratinocytes.

FIGURE 10 is a graphical representation of the relationship between oligonucleotide chain length, Tm and effect on inhibition of ICAM-1 expression.

FIGURE 11 is a graphical representation of the effect of selected antisense oligonucleotides on ICAM-1 mediated adhesion of DMSO differentiated HL-60 cells to control and tumor necrosis factor treated human umbilical vein endothelial cells.

FIGURE 12 is a graphical representation of the effects of selected antisense oligonucleotides on ELAM-1 expression on tumor necrosis factor-treated human umbilical vein endothelial cells.

FIGURE 13 is a graphical representation of the human ELAM-1 mRNA showing target sites of antisense oligonucleotides.

FIGURE 14 is a graphical representation of the human VCAM-1 mRNA showing target sites of antisense oligonucleotides.

FIGURE 15 is a line graph showing inhibition of ICAM-1 expression in C8161 human melanoma cells following treatment with antisense oligonucleotides complementary to ICAM-1.

FIGURE 16 is a bar graph showing the effect of ISIS 3082 on dextran sulfate (DSS)-induced inflammatory bowel disease.

SUMMARY OF THE INVENTION

In accordance with the present invention, oligonucleotides are provided which specifically hybridize with nucleic acids encoding intercellular adhesion molecule-1 (ICAM-1), vascular cell adhesion molecule-1 (VCAM-1) and endothelial leukocyte adhesion molecule-1 (ELAM-1). The oligonucleotides are designed to bind either directly to mRNA or to a selected DNA portion forming a triple stranded structure, thereby modulating the amount of mRNA made from

the gene. This relationship is commonly denoted as "antisense."

Oligonucleotides are commonly used as research reagents and diagnostics. For example, antisense oligonucleotides, which are able to inhibit gene expression with exquisite specificity, are often used by those of ordinary skill to elucidate the function of particular genes, for example to distinguish between the functions of various members of a biological pathway. This specific inhibitory effect has, therefore, been harnessed for research use. This specificity and sensitivity is also harnessed by those of skill in the art for diagnostic uses.

It is preferred to target specific genes for antisense attack. "Targeting" an oligonucleotide to the associated ribonucleotides, in the context of this invention, is a multistep process. The process usually begins with identifying a nucleic acid sequence whose function is to be modulated. This may be, as examples, a cellular gene (or mRNA made from the gene) whose expression is associated with a particular disease state, or a foreign nucleic acid from an infectious agent. In the present invention, the target is a cellular gene associated with a particular disease state. The targeting process also includes determination of a site or sites within this region for the oligonucleotide interaction to occur such that the desired effect, either detection of or modulation of expression of the protein will result. Once the target site or sites have been identified, oligonucleotides are chosen which are sufficiently complementary to the target, i.e., hybridize sufficiently well and with sufficient specificity, to give the desired effect.

It has been discovered that the genes coding for ICAM-1, VCAM-1 and ELAM-1 are particularly useful for this approach. Inhibition of ICAM-1, VCAM-1 and ELAM-1

expression is expected to be useful for the treatment of inflammatory diseases, diseases with an inflammatory component, allograft rejection, psoriasis and other skin diseases, inflammatory bowel disease, cancers and their metastasis, and viral infections.

Methods of modulating cell adhesion comprising contacting the animal with an oligonucleotide hybridizable with nucleic acids encoding a protein capable of modulating cell adhesion are provided. Oligonucleotides hybridizable with an RNA or DNA encoding ICAM-1, VCAM-1 and ELAM-1 are preferred.

The present invention is also useful in diagnostics and in research. Since the oligonucleotides of this invention hybridize to ICAM-1, ELAM-1 or VCAM-1, sandwich and other assays can easily be constructed to exploit this fact. Provision of means for detecting hybridization of an oligonucleotide with one of these intercellular adhesion molecules present in a sample suspected of containing it can routinely be accomplished. Such provision may include enzyme conjugation, radiolabelling or any other suitable detection system. A number of assays may be formulated employing the present invention, which assays will commonly comprise contacting a tissue sample with a detectably labeled oligonucleotide of the present invention under conditions selected to permit hybridization and measuring such hybridization by detection of the label.

For example, radiolabeled oligonucleotides can be prepared by ^{32}P labeling at the 5' end with polynucleotide kinase. Sambrook et al., *Molecular Cloning. A Laboratory Manual*, Cold Spring Harbor Laboratory Press, 1989, Volume 2, pg. 10.59. Radiolabeled oligonucleotides are then contacted with tissue or cell samples suspected of containing an intercellular adhesion molecule and the sample is washed to remove unbound oligonucleotide. Radioactivity remaining in

the sample indicates bound oligonucleotide (which in turn indicates the presence of an intercellular adhesion molecule) and can be quantitated using a scintillation counter or other routine means. Expression of these proteins can then be detected.

Radiolabeled oligonucleotides of the present invention can also be used to perform autoradiography of tissues to determine the localization, distribution and quantitation of intercellular adhesion molecules for research, diagnostic or therapeutic purposes. In such studies, tissue sections are treated with radiolabeled oligonucleotide and washed as described above, then exposed to photographic emulsion according to routine autoradiography procedures. The emulsion, when developed, yields an image of silver grains over the regions expressing a intercellular adhesion molecule. Quantitation of the silver grains permits expression of these molecules to be detected and permits targeting of oligonucleotides to these areas.

Analogous assays for fluorescent detection of expression of intercellular adhesion molecules can be developed using oligonucleotides of the present invention which are conjugated with fluorescein or other fluorescent tag instead of radiolabeling. Such conjugations are routinely accomplished during solid phase synthesis using fluorescently labeled amidites or CPG (e.g., fluorescein-labeled amidites and CPG available from Glen Research, Sterling VA).

Each of these assay formats is known in the art. One of skill could easily adapt these known assays for detection of expression of intercellular adhesion molecules in accordance with the teachings of the invention providing a novel and useful means to detect expression of these molecules. Antisense oligonucleotide inhibition of the expression of intercellular adhesion molecules *in vitro* is

useful as a means to determine a proper course of therapeutic treatment. For example, before a patient is treated with an oligonucleotide composition of the present invention, cells, tissues or a bodily fluid from the patient can be treated with the oligonucleotide and inhibition of expression of intercellular adhesion molecules can be assayed. Effective *in vitro* inhibition of the expression of molecules in the sample indicates that the expression will also be modulated *in vivo* by this treatment.

Kits for detecting the presence or absence of intercellular adhesion molecules may also be prepared. Such kits include an oligonucleotide targeted to ICAM-1, ELAM-1 or VCAM-1.

The oligonucleotides of this invention may also be used for research purposes. Thus, the specific hybridization exhibited by the oligonucleotides may be used for assays, purifications, cellular product preparations, and in other methodologies which may be appreciated by persons of ordinary skill in the art.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Antisense oligonucleotides hold great promise as therapeutic agents for the treatment of many human diseases. Oligonucleotides specifically bind to the complementary sequence of either pre-mRNA or mature mRNA, as defined by Watson-Crick base pairing, inhibiting the flow of genetic information from DNA to protein. The properties of antisense oligonucleotides, which make them specific for their target sequence, also make them extraordinarily versatile. Because antisense oligonucleotides are long chains of four monomeric units they may be readily synthesized for any target RNA sequence. Numerous recent studies have documented the utility of antisense oligonucleotides as biochemical tools for studying target

proteins. Rothenberg et al., *J. Natl. Cancer Inst.* **1989**, 81, 1539-1544; Zon, G. *Pharmaceutical Res.* **1988**, 5, 539-549). Because of recent advances in synthesis of nuclease resistant oligonucleotides, which exhibit enhanced cell uptake, it is now possible to consider the use of antisense oligonucleotides as a novel form of therapeutics.

Antisense oligonucleotides offer an ideal solution to the problems encountered in prior art approaches. They can be designed to selectively inhibit a given isoenzyme, they inhibit the production of the enzyme, and they avoid non-specific mechanisms such as free radical scavenging or binding to multiple receptors. A complete understanding of enzyme mechanisms or receptor-ligand interactions is not needed to design specific inhibitors.

DESCRIPTION OF TARGETS

The acute infiltration of neutrophils into the site of inflammation appears to be due to increased expression of GMP-140, ELAM-1 and ICAM-1 on the surface of endothelial cells. The appearance of lymphocytes and monocytes during the later stages of an inflammatory reaction appear to be mediated by VCAM-1 and ICAM-1. ELAM-1 and GMP-140 are transiently expressed on vascular endothelial cells, while VCAM-1 and ICAM-1 are chronically expressed.

Human ICAM-1 is encoded by a 3.3-kb mRNA resulting in the synthesis of a 55,219 dalton protein (Figure 1). ICAM-1 is heavily glycosylated through N-linked glycosylation sites. The mature protein has an apparent molecular mass of 90 kDa as determined by SDS-polyacrylamide gel electrophoresis. Staunton et al., *Cell* **1988**, 52, 925-933. ICAM-1 is a member of the immunoglobulin supergene family, containing 5 immunoglobulin-like domains at the amino terminus, followed by a transmembrane domain and a cytoplasmic domain. The primary binding site for LFA-1 and

rhinovirus are found in the first immunoglobulin-like domain. However, the binding sites appear to be distinct. Staunton et al., *Cell* **1990**, 61, 243-354. Recent electron micrographic studies demonstrate that ICAM-1 is a bent rod 18.7 nm in length and 2 to 3 nm in diameter. Staunton et al., *Cell* **1990**, 61, 243-254.

ICAM-1 exhibits a broad tissue and cell distribution, and may be found on white blood cells, endothelial cells, fibroblast, keratinocytes and other epithelial cells. The expression of ICAM-1 can be regulated on vascular endothelial cells, fibroblasts, keratinocytes, astrocytes and several cell lines by treatment with bacterial lipopolysaccharide and cytokines such as interleukin-1, tumor necrosis factor, gamma-interferon, and lymphotoxin. *See, e.g.*, Frohman et al., *J. Neuroimmunol.* **1989**, 23, 117-124. The molecular mechanism for increased expression of ICAM-1 following cytokine treatment has not been determined. ELAM-1 is a 115-kDa membrane glycoprotein (Figure 2) which is a member of the selectin family of membrane glycoproteins. Bevilacqua et al., *Science* **1989**, 243, 1160-1165. The amino terminal region of ELAM-1 contains sequences with homologies to members of lectin-like proteins, followed by a domain similar to epidermal growth factor, followed by six tandem 60-amino acid repeats similar to those found in complement receptors 1 and 2. These features are also shared by GMP-140 and MEL-14 antigen, a lymphocyte homing antigen. ELAM-1 is encoded for by a 3.9-kb mRNA. The 3'-untranslated region of ELAM-1 mRNA contains several sequence motifs ATTTA which are responsible for the rapid turnover of cellular mRNA consistent with the transient nature of ELAM-1 expression.

ELAM-1 exhibits a limited cellular distribution in that it has only been identified on vascular endothelial cells. Like ICAM-1, ELAM-1 is inducible by a number of cytokines

including tumor necrosis factor, interleukin-1 and lymphotoxin and bacterial lipopolysaccharide. In contrast to ICAM-1, ELAM-1 is not induced by gamma-interferon. Bevilacqua et al., *Proc. Natl. Acad. Sci. USA* **1987**, 84, 9238-9242; Wellicome et al., *J. Immunol.* **1990**, 144, 2558-2565. The kinetics of ELAM-1 mRNA induction and disappearance in human umbilical vein endothelial cells precedes the appearance and disappearance of ELAM-1 on the cell surface. As with ICAM-1, the molecular mechanism for ELAM-1 induction is not known.

VCAM-1 is a 110-kDa membrane glycoprotein encoded by a 3.2-kb mRNA (Figure 3). VCAM-1 appears to be encoded by a single-copy gene which can undergo alternative splicing to yield products with either six or seven immunoglobulin domains. Osborn et al., *Cell* **1989**, 59, 1203-1211. The receptor for VCAM-1 is proposed to be CD29 (VLA-4) as demonstrated by the ability of monoclonal antibodies to CD29 to block adherence of Ramos cells to VCAM-1. VCAM-1 is expressed primarily on vascular endothelial cells. Like ICAM-1 and ELAM-1, expression of VCAM-1 on vascular endothelium is regulated by treatment with cytokines. Rice and Bevilacqua, *Science* **1989**, 246, 1303-1306; Rice et al., *J. Exp. Med.* **1990**, 171, 1369-1374. Increased expression appears to be due to induction of the mRNA.

For therapeutics, an animal suspected of having a disease which can be treated by decreasing the expression of ICAM-1, VCAM-1 and ELAM-1 is treated by administering oligonucleotides in accordance with this invention. Oligonucleotides may be formulated in a pharmaceutical composition, which may include carriers, thickeners, diluents, buffers, preservatives, surface active agents, liposomes or lipid formulations and the like, in addition to the oligonucleotide. Pharmaceutical compositions may also include one or more active ingredients such as antimicrobial

agents, anti-inflammatory agents, anesthetics, and the like, in addition to oligonucleotide.

The pharmaceutical composition may be administered in a number of ways depending on whether local or systemic treatment is desired, and on the area to be treated. Administration may be topically (including ophthalmically, vaginally, rectally, intranasally), orally, by inhalation, or parenterally, for example by intravenous drip, subcutaneous, intraperitoneal or intramuscular injection. Formulations for topical administration may include ointments, lotions, creams, gels, drops, suppositories, sprays, liquids and powders. Conventional pharmaceutical carriers, aqueous, powder or oily bases, thickeners and the like may be necessary or desirable. Coated condoms or gloves may also be useful.

Compositions for oral administration include powders or granules, suspensions or solutions in water or non-aqueous media, capsules, sachets, or tablets. Thickeners, flavorings, diluents, emulsifiers, dispersing aids or binders may be desirable.

Formulations for parenteral administration may include sterile aqueous solutions, which may also contain buffers, liposomes, diluents and other suitable additives.

Dosing is dependent on severity and responsiveness of the condition to be treated, but will normally be one or more doses per day, with course of treatment lasting from several days to several months or until a cure is effected or a diminution of disease state is achieved. Persons of ordinary skill can easily determine optimum dosages, dosing methodologies and repetition rates.

The present invention employs oligonucleotides for use in antisense inhibition of the function of RNA and DNA corresponding to proteins capable of modulating inflammatory cell adhesion. In the context of this invention, the term

"oligonucleotide" refers to an oligomer or polymer of ribonucleic acid or deoxyribonucleic acid. This term includes oligomers consisting of naturally occurring bases, sugars and intersugar (backbone) linkages as well as oligomers having non-naturally occurring portions, which function similarly. Such modified or substituted oligonucleotides are often preferred over native forms because of properties such as, for example, enhanced cellular uptake and increased stability in the presence of nucleases.

Specific examples of some preferred oligonucleotides envisioned for this invention may contain phosphorothioates, phosphotriesters, methyl phosphonates, short chain alkyl or cycloalkyl intersugar linkages or short chain heteroatomic or heterocyclic intersugar linkages. Most preferred are those with CH_2-NH-O-CH_2, CH_2-N(CH_3)-O-CH_2, CH_2-O-N(CH_3)-CH_2, CH_2-N(CH_3)-N(CH_3)-CH_2 and O-N(CH_3)-CH_2-CH_2 backbones (where phosphodiester is O-P-O-CH_2). Also preferred are oligonucleotides having morpholino backbone structures. Summerton, J.E. and Weller, D.D., U.S. Patent 5,034,506. In other preferred embodiments, such as the protein-nucleic acid (PNA) backbone, the phosphodiester backbone of the oligonucleotide may be replaced with a polyamide backbone, the bases being bound directly or indirectly to the aza nitrogen atoms of the polyamide backbone. P.E. Nielsen, M. Egholm, R.H. Berg, O. Buchardt, *Science* **1991**, 254, 1497. Other preferred oligonucleotides may contain alkyl and halogen-substituted sugar moieties comprising one of the following at the 2' position: OH, SH, SCH_3, F, OCN, $O(CH_2)_nNH_2$ or $O(CH_2)_nCH_3$ where n is from 1 to about 10; C_1 to C_{10} lower alkyl, substituted lower alkyl, alkaryl or aralkyl; Cl; Br; CN; CF_3; OCF_3; O-, S-, or N-alkyl; O-, S-, or N-alkenyl; $SOCH_3$; SO_2CH_3; ONO_2; NO_2; N_3; NH_2; heterocycloalkyl; heterocycloalkaryl; aminoalkylamino; polyalkylamino;

substituted silyl; an RNA cleaving group; a conjugate; a reporter group; an intercalator; a group for improving the pharmacokinetic properties of an oligonucleotide; or a group for improving the pharmacodynamic properties of an oligonucleotide and other substituents having similar properties. Oligonucleotides may also have sugar mimetics such as cyclobutyls in place of the pentofuranosyl group.

The oligonucleotides in accordance with this invention preferably comprise from about 3 to about 50 nucleic acid base units. It is more preferred that such oligonucleotides comprise from about 8 to 25 nucleic acid base units, and still more preferred to have from about 12 to 22 nucleic acid base units. As will be appreciated, a nucleic acid base unit is a base-sugar combination suitably bound to an adjacent nucleic acid base unit through phosphodiester or other bonds.

The oligonucleotides used in accordance with this invention may be conveniently and routinely made through the well-known technique of solid phase synthesis. Equipment for such synthesis is sold by several vendors including Applied Biosystems. Any other means for such synthesis may also be employed; however, the actual synthesis of the oligonucleotides are well within the talents of the routineer. It is also well known to use similar techniques to prepare other oligonucleotides such as the phosphorothioates and alkylated derivatives.

In accordance with this invention, persons of ordinary skill in the art will understand that messenger RNA identified by the open reading frames (ORFs) of the DNA from which they are transcribed includes not only the information from the ORFs of the DNA, but also associated ribonucleotides which form regions known to such persons as the 5'-untranslated region, the 3'- untranslated region, and intervening sequence ribonucleotides. Thus,

oligonucleotides may be formulated in accordance with this invention, which are targeted wholly or in part to these associated ribonucleotides as well as to the informational ribonucleotides. In preferred embodiments, the oligonucleotide is specifically hybridizable with a transcription initiation site, a translation initiation site, an intervening sequence and sequences in the 3'-untranslated region.

In accordance with this invention, the oligonucleotide is specifically hybridizable with portions of nucleic acids encoding a protein involved in the adhesion of white blood cells either to other white blood cells or other cell types. In preferred embodiments, said proteins are intercellular adhesion molecule-1, vascular cell adhesion molecule-1 and endothelial leukocyte adhesion molecule-1. Oligonucleotides comprising the corresponding sequence, or part thereof, are useful in the invention. For example, Figure 1 is a human intercellular adhesion molecule-1 mRNA sequence. A preferred sequence segment, which may be useful in whole or in part, is:

5' 3'	SEQ ID NO:
TGGGAGCCATAGCGAGGC	1
GAGGAGCTCAGCGTCGACTG	2
GACACTCAATAAATAGCTGGT	3
GAGGCTGAGGTGGGAGGA	4
CGATGGGCAGTGGGAAAG	5
GGGCGCGTGATCCTTATAGC	6
CATAGCGAGGCTGAGGTTGC	7
CGGGGGCTGCTGGGAGCCAT	8
TCAGGGAGGCGTGGCTTGTG	13
CCTGTCCCGGGATAGGTTCA	14
TTGAGAAAGCTTTATTAACT	16
CCCCCACCACTTCCCCTCTC.	15

Figure 2 is a human endothelial leukocyte adhesion molecule-1 mRNA sequence. A preferred sequence segment, which may be useful in whole or in part, is:

5'	3'	SEQ ID NO:
CAATCATGACTTCAAGAGTTCT		28
TCACTGCTGCCTCTGTCTCAGG		73
TGATTCTTTTGAACTTAAAAGGA		74
TTAAAGGATGTAAGAAGGCT		75
CATAAGCACATTTATTGTC		76
TTTTGGGAAGCAGTTGTTCA		77
AACTGTGAAGCAATCATGACT		78
CCTTGAGTGGTGCATTCAACCT		79
AATGCTTGCTCACACAGGCATT		80.

Figure 3 is a human vascular cell adhesion molecule-1 mRNA sequence. A preferred sequence segment, which may be useful in whole or in part, is:

5'	3'	SEQ ID NO:
CCAGGCATTTTAAGTTGCTGT		40
CCTGAAGCCAGTGAGGCCCG		41
GATGAGAAAATAGTGGAACCA		42
CTGAGCAAGATATCTAGAT		43
CTACACTTTTGATTTCTGT		44
TTGAACATATCAAGCATTAGCT		45
TTTACATATGTACAAATTATGT		46
AATTATCACTTTACTATACAAA		47
AGGGCTGACCAAGACGGTTGT		48.

While the illustrated sequences are believed to be accurate, the present invention is directed to the correct sequences, should errors be found. Oligonucleotides useful in the invention comprise one of these sequences, or part thereof. Thus, it is preferred to employ any of these oligonucleotides as set forth above or any of the similar

oligonucleotides which persons of ordinary skill in the art can prepare from knowledge of the preferred antisense targets for the modulation of the synthesis of inflammatory cell adhesion molecules.

Several preferred embodiments of this invention are exemplified in accordance with the following nonlimiting examples. The target mRNA species for modulation relates to intercellular adhesion molecule-1, endothelial leukocyte adhesion molecule-1, and vascular cell adhesion molecule-1. Persons of ordinary skill in the art will appreciate that the present invention is not so limited, however, and that it is generally applicable. The inhibition or modulation of production of the ICAM-1 and/or ELAM-1 and/or VCAM-1 are expected to have significant therapeutic benefits in the treatment of disease. In order to assess the effectiveness of the compositions, an assay or series of assays is performed.

One type of disorder suitable for treatment with the oligonucleotides of the present invention are in inflammatory ophthalmic disorders including redness and inflammation caused by allergens and allergic reactions. The oligonucleotides can also be used as an adjuvant to antibiotic treatment of conjunctivitis. In a preferred embodiment, the oligonucleotides are used to preserve corneal explants *ex vivo* and to prevent corneal allograft rejection. These oligonucleotides may be placed in solution and administered as eyedrops for topical treatment of the allograft. The solution is suitable for use as a storage medium for corneal explants, and is administered in eye drop form following corneal transplant to prevent corneal allograft rejection.

The following examples are provided for illustrative purposes only and are not intended to limit the invention.

EXAMPLES

Example 1

Expression of ICAM-1, VCAM-1 and ELAM-1 on the surface of cells can be quantitated using specific monoclonal antibodies in an ELISA. Cells are grown to confluence in 96 well microtiter plates. The cells are stimulated with either interleukin-1 or tumor necrosis factor for 4 to 8 hours to quantitate ELAM-1 and 8 to 24 hours to quantitate ICAM-1 and VCAM-1. Following the appropriate incubation time with the cytokine, the cells are gently washed three times with a buffered isotonic solution containing calcium and magnesium such as Dulbecco's phosphate buffered saline (D-PBS). The cells are then directly fixed on the microtiter plate with 1 to 2% paraformaldehyde diluted in D-PBS for 20 minutes at 25°C. The cells are washed again with D-PBS three times. Nonspecific binding sites on the microtiter plate are blocked with 2% bovine serum albumin in D-PBS for 1 hour at 37°C. Cells are incubated with the appropriate monoclonal antibody diluted in blocking solution for 1 hour at 37°C. Unbound antibody is removed by washing the cells three times with D-PBS. Antibody bound to the cells is detected by incubation with a 1:1000 dilution of biotinylated goat anti-mouse IgG (Bethesda Research Laboratories, Gaithersburg, MD) in blocking solution for 1 hour at 37°C. Cells are washed three times with D-PBS and then incubated with a 1:1000 dilution of streptavidin conjugated to ß-galactosidase (Bethesda Research Laboratories) for 1 hour at 37°C. The cells are washed three times with D-PBS for 5 minutes each. The amount of ß-galactosidase bound to the specific monoclonal antibody is determined by developing the plate in a solution of 3.3 mM chlorophenolred-ß-D-galactopyranoside, 50 mM sodium phosphate, 1.5 mM $MgCl_2$; pH=7.2 for 2 to 15 minutes at 37°C. The concentration of the product is determined by measuring

the absorbance at 575 nm in an ELISA microtiter plate reader.

An example of the induction of ICAM-1 observed following stimulation with either interleukin-1ß or tumor necrosis factor α in several human cell lines is shown in Figure 4. Cells were stimulated with increasing concentrations of interleukin-1 or tumor necrosis factor for 15 hours and processed as described above. ICAM-1 expression was determined by incubation with a 1:1000 dilution of the monoclonal antibody 84H10 (Amac Inc., Westbrook, ME). The cell lines used were passage 4 human umbilical vein endothelial cells (HUVEC), a human epidermal carcinoma cell line (A431), a human melanoma cell line (SK-MEL-2) and a human lung carcinoma cell line (A549). ICAM-1 was induced on all the cell lines, however, tumor necrosis factor was more effective than interleukin-1 in induction of ICAM-1 expression on the cell surface (Figure 4).

Screening antisense oligonucleotides for inhibition of ICAM-1, VCAM-1 or ELAM-1 expression is performed as described above with the exception of pretreatment of cells with the oligonucleotides prior to challenge with the cytokines. An example of antisense oligonucleotide inhibition of ICAM-1 expression is shown in Figure 5. Human umbilical vein endothelial cells (HUVEC) were treated with increasing concentration of oligonucleotide diluted in Opti MEM (GIBCO, Grand Island, NY) containing 8 μM N-[1-(2,3-dioleyloxy) propyl]-N,N,N-trimethylammonium chloride (DOTMA) for 4 hours at 37°C to enhance uptake of the oligonucleotides. The medium was removed and replaced with endothelial growth medium (EGM-UV; Clonetics, San Diego, CA) containing the indicated concentration of oligonucleotide for an additional 4 hours. Interleukin-1β was added to the cells at a concentration of 5 units/ml and incubated for 14 hours at 37°C. The cells were quantitated for ICAM-1

expression using a 1:1000 dilution of the monoclonal antibody 84H10 as described above. The oligonucleotides used were:

COMPOUND 1 - (ISIS 1558) a phosphodiester oligonucleotide designed to hybridize with position 64-80 of the mRNA covering the AUG initiation of translation codon having the sequence 5'-TGGGAGCCATAGCGAGGC-3' (SEQ ID NO: 1).

COMPOUND 2 - (ISIS 1570) a phosphorothioate containing oligonucleotide corresponding to the same sequence as COMPOUND 1.

COMPOUND 3 - a phosphorothioate oligonucleotide complementary to COMPOUND 1 and COMPOUND 2 exhibiting the sequence 5'-GCCTCGCTATGGCTCCCA-3' (SEQ ID NO: 81).

COMPOUND 4 - (ISIS 1572) a phosphorothioate containing oligonucleotide designed to hybridize to positions 2190-2210 of the mRNA in the 3' untranslated region containing the sequence 5'-GACACTCAATAAATAGCTGGT-3' (SEQ ID NO: 3).

COMPOUND 5 - (ISIS 1821) a phosphorothioate containing oligonucleotide designed to hybridize to human 5-lipoxygenase mRNA used as a control containing the sequence 5'-CATGGCGCGGGCCGCGGG-3' (SEQ ID NO: 82).

The phosphodiester oligonucleotide targeting the AUG initiation of translation region of the human ICAM-1 mRNA (COMPOUND 1) did not inhibit expression of ICAM-1; however, the corresponding phosphorothioate containing oligonucleotide (COMPOUND 2) inhibited ICAM-1 expression by 70% at a concentration of 0.1 μM and 90% at 1 μM concentration (Figure 4). The increased potency of the phosphorothioate oligonucleotide over the phosphodiester is probably due to increased stability. The sense strand to COMPOUND 2, COMPOUND 3, modestly inhibited ICAM-1 expression at 10 μM. If COMPOUND 2 was prehybridized to COMPOUND 3 prior to addition to the cells, the effects of COMPOUND 2 on ICAM-1 expression were attenuated suggesting that the

activity of COMPOUND 2 was due to antisense oligonucleotide effect, requiring hybridization to the mRNA. The antisense oligonucleotide directed against 3' untranslated sequences (COMPOUND 4) inhibited ICAM-1 expression 62% at a concentration of 1 μM (Figure 5). The control oligonucleotide, targeting human 5-lipoxygenase (COMPOUND 5) reduced ICAM-1 expression by 20%. These data demonstrate that oligonucleotides are capable of inhibiting ICAM-1 expression on human umbilical vein endothelial cells and suggest that the inhibition of ICAM-1 expression is due to an antisense activity.

The antisense oligonucleotide COMPOUND 2 at a concentration of 1 μM inhibits expression of ICAM-1 on human umbilical vein endothelial cells stimulated with increasing concentrations of tumor necrosis factor and interleukin-1 (Figure 6). These data demonstrate that the effects of COMPOUND 2 are not specific for interleukin-1 stimulation of cells.

Analogous assays can also be used to demonstrate inhibition of ELAM-1 and VCAM-1 expression by antisense oligonucleotides.

Example 2

A second cellular assay which can be used to demonstrate the effects of antisense oligonucleotides on ICAM-1, VCAM-1 or ELAM-1 expression is a cell adherence assay. Target cells are grown as a monolayer in a multiwell plate, treated with oligonucleotide followed by cytokine. The adhering cells are then added to the monolayer cells and incubated for 30 to 60 minutes at 37°C and washed to remove nonadhering cells. Cells adhering to the monolayer may be determined either by directly counting the adhering cells or prelabeling the cells with a radioisotope such as ^{51}Cr and quantitating the radioactivity associated with the monolayer

as described. Dustin and Springer, *J. Cell Biol.* **1988**, 107, 321-331. Antisense oligonucleotides may target either ICAM-1, VCAM-1 or ELAM-1 in the assay.

An example of the effects of antisense oligonucleotides targeting ICAM-1 mRNA on the adherence of DMSO differentiated HL-60 cells to tumor necrosis factor treated human umbilical vein endothelial cells is shown in Figure 7. Human umbilical vein endothelial cells were grown to 80% confluence in 12 well plates. The cells were treated with 2 μM oligonucleotide diluted in Opti-MEM containing 8 μM DOTMA for 4 hours at 37°C. The medium was removed and replaced with fresh endothelial cell growth medium (EGM-UV) containing 2 μM of the indicated oligonucleotide and incubated 4 hours at 37°C. Tumor necrosis factor, 1 ng/ml, was added to cells as indicated and cells incubated for an additional 19 hours. The cells were washed once with EGM-UV and 1.6 x 10^6 HL-60 cells differentiated for 4 days with 1.3% DMSO added. The cells were allowed to attach for 1 hour at 37°C and gently washed 4 times with Dulbecco's phosphate-buffered saline (D-PBS) warmed to 37°C. Adherent cells were detached from the monolayer by addition of 0.25 ml of cold (4EC) phosphate-buffered saline containing 5 mM EDTA and incubated on ice for 5 minutes. The number of cells removed by treatment with EDTA was determined by counting with a hemocytometer. Endothelial cells detached from the monolayer by EDTA treatment could easily be distinguished from HL-60 cells by morphological differences. In the absence of tumor necrosis factor, 3% of the HL-60 cells bound to the endothelial cells. Treatment of the endothelial cell monolayer with 1 ng/ml tumor necrosis factor increased the number of adhering cells to 59% of total cells added (Figure 7). Treatment with the antisense oligonucleotide COMPOUND 2 or the control oligonucleotide COMPOUND 5 did not change the number of cells adhering to

the monolayer in the absence of tumor necrosis factor treatment (Figure 7). The antisense oligonucleotide, COMPOUND 2 reduced the number of adhering cells from 59% of total cells added to 17% of the total cells added (Figure 7). In contrast, the control oligonucleotide COMPOUND 5 did not significantly reduce the number of cells adhering to the tumor necrosis factor treated endothelial monolayer, i.e., 53% of total cells added for COMPOUND 5 treated cells versus 59% for control cells.

These data indicate that antisense oligonucleotides are capable of inhibiting ICAM-1 expression on endothelial cells and that inhibition of ICAM-1 expression correlates with a decrease in the adherence of a neutrophil-like cell to the endothelial monolayer in a sequence specific fashion. Because other molecules also mediate adherence of white blood cells to endothelial cells, such as ELAM-1, and VCAM-1 it is not expected that adherence would be completely blocked.

Example 3

Synthesis and characterization of oligonucleotides

Unmodified DNA oligonucleotides were synthesized on an automated DNA synthesizer (Applied Biosystems model 380B) using standard phosphoramidite chemistry with oxidation by iodine. ß-cyanoethyldiisopropyl-phosphoramidites were purchased from Applied Biosystems (Foster City, CA). For phosphorothioate oligonucleotides, the standard oxidation bottle was replaced by a 0.2 M solution of 3H-1,2-benzodithiole-3-one 1,1-dioxide in acetonitrile for the stepwise thiation of the phosphite linkages. The thiation cycle wait step was increased to 68 seconds and was followed by the capping step.

2'-O-methyl phosphorothioate oligonucleotides were synthesized using 2'-O-methyl ß-cyanoethyldiisopropyl-

phosphoramidites (Chemgenes, Needham MA) and the standard cycle for unmodified oligonucleotides, except the wait step after pulse delivery of tetrazole and base was increased to 360 seconds. The 3'-base used to start the synthesis was a 2'-deoxyribonucleotide.

2'-fluoro phosphorothioate oligonucleotides were synthesized using 5'-dimethoxytrityl-3'-phosphoramidites and prepared as disclosed in U.S. patent application Serial No. 463,358, filed January 11, 1990, and 566,977, filed August 13, 1990, which are assigned to the same assignee as the instant application and which are incorporated by reference herein. The 2'-fluoro oligonucleotides were prepared using phosphoramidite chemistry and a slight modification of the standard DNA synthesis protocol: deprotection was effected using methanolic ammonia at room temperature.

After cleavage from the controlled pore glass column (Applied Biosystems) and deblocking in concentrated ammonium hydroxide at 55EC for 18 hours, the oligonucleotides were purified by precipitation twice out of 0.5 M NaCl with 2.5 volumes ethanol. Analytical gel electrophoresis was accomplished in 20% acrylamide, 8 M urea, 45 mM Tris-borate buffer, pH 7.0. Oligodeoxynucleotides and phosphorothioate oligonucleotides were judged from electrophoresis to be greater than 80% full length material.

RNA oligonucleotide synthesis was performed on an ABI model 380B DNA synthesizer. The standard synthesis cycle was modified by increasing the wait step after the pulse delivery of tetrazole to 900 seconds. The bases were deprotected by incubation in methanolic ammonia overnight. Following base deprotections the oligonucleotides were dried *in vacuo*. The t-butyldimethylsilyl protecting the 2' hydroxyl was removed by incubating the oligonucleotide in 1 M tetrabutylammonium-fluoride in tetrahydrofuran overnight. The RNA oligonucleotides were further purified on C_{18} Sep-Pak

cartridges (Waters, Division of Millipore Corp., Milford MA) and ethanol precipitated.

The relative amounts of phosphorothioate and phosphodiester linkages obtained by this synthesis were periodically checked by ^{31}P NMR spectroscopy. The spectra were obtained at ambient temperature using deuterium oxide or dimethyl sulfoxide-d_6 as solvent. Phosphorothioate samples typically contained less than one percent of phosphodiester linkages.

Secondary evaluation was performed with oligonucleotides purified by trityl-on HPLC on a PRP-1 column (Hamilton Co., Reno, Nevada) using a gradient of acetonitrile in 50 mM triethylammonium acetate, pH 7.0 (4% to 32% in 30 minutes, flow rate = 1.5 ml/min). Appropriate fractions were pooled, evaporated and treated with 5% acetic acid at ambient temperature for 15 minutes. The solution was extracted with an equal volume of ethyl acetate, neutralized with ammonium hydroxide, frozen and lyophilized. HPLC-purified oligonucleotides were not significantly different in potency from precipitated oligonucleotides, as judged by the ELISA assay for ICAM-1 expression.

Example 4

Cell culture and treatment with oligonucleotides

The human lung carcinoma cell line A549 was obtained from the American Type Culture Collection (Bethesda MD). Cells were grown in Dulbecco's Modified Eagle's Medium (Irvine Scientific, Irvine CA) containing 1 gm glucose/liter and 10% fetal calf serum (Irvine Scientific). Human umbilical vein endothelial cells (HUVEC) (Clonetics, San Diego CA) were cultured in EGM-UV medium (Clonetics). HUVEC were used between the second and sixth passages. Human epidermal carcinoma A431 cells were obtained from the American Type Culture Collection and cultured in DMEM with

4.5 g/l glucose. Primary human keratinocytes were obtained from Clonetics and grown in KGM (Keratinocyte growth medium, Clonetics).

Cells grown in 96-well plates were washed three times with Opti-MEM (GIBCO, Grand Island, NY) prewarmed to 37°C. 100 μl of Opti-MEM containing either 10 μg/ml N-[1-(2,3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride (DOTMA, Bethesda Research Labs, Bethesda MD) in the case of HUVEC cells or 20 μg/ml DOTMA in the case of A549 cells was added to each well. Oligonucleotides were sterilized by centrifugation through 0.2 μm Centrex cellulose acetate filters (Schleicher and Schuell, Keene, NH). Oligonucleotides were added as 20x stock solution to the wells and incubated for 4 hours at 37°C. Medium was removed and replaced with 150 μl of the appropriate growth medium containing the indicated concentration of oligonucleotide. Cells were incubated for an additional 3 to 4 hours at 37°C then stimulated with the appropriate cytokine for 14 to 16 hours, as indicated. ICAM-1 expression was determined as described in Example 1. The presence of DOTMA during the first 4 hours incubation with oligonucleotide increased the potency of the oligonucleotides at least 100-fold. This increase in potency correlated with an increase in cell uptake of the oligonucleotide.

Example 5

ELISA screening of additional antisense oligonucleotides for activity against ICAM-1 gene expression in Interleukin-1ß-stimulated cells

Antisense oligonucleotides were originally designed that would hybridize to five target sites on the human ICAM-1 mRNA. Oligonucleotides were synthesized in both phosphodiester (P=O; ISIS 1558, 1559, 1563, 1564 and 1565)

and phosphorothioate (P=S; ISIS 1570, 1571, 1572, 1573, and 1574) forms. The oligonucleotides are shown in Table 1.

Table 1

ANTISENSE OLIGONUCLEOTIDES WHICH TARGET HUMAN ICAM-1

ISIS NO.	SEQ ID NO.	TARGET REGION	MODIFICATION
1558	1	AUG Codon (64-81)	P=O
1559	2	5'-Untranslated (32-49)	P=O
1563	3	3'-Untranslated (2190-3010)	P=O
1564	4	3'-Untranslated (2849-2866)	P=O
1565	5	Coding Region (1378-1395)	P=O
1570	1	AUG Codon (64-81)	P=S
1571	2	5'-Untranslated (32-49)	P=S
1572	3	3'-Untranslated (2190-3010)	P=S
1573	4	3'-Untranslated (2849-2866)	P=S
1574	5	Coding Region (1378-1395)	P=S
1930	6	5'-Untranslated (1-20)	P=S
1931	7	AUG Codon (55-74)	P=S
1932	8	AUG Codon (72-91)	P=S
1933	9	Coding Region (111-130)	P=S
1934	10	Coding Region (351-370)	P=S
1935	11	Coding Region (889-908)	P=S
1936	12	Coding Region (1459-1468)	P=S
1937	13	Termination Codon (1651-1687)	P=S
1938	14	Termination Codon (1668-1687)	P=S
1939	15	3'-Untranslated (1952-1971)	P=S
1940	16	3'-Untranslated (2975-2994)	P=S
2149	17	AUG Codon (64-77)	P=S
2163	18	AUG Codon (64-75)	P=S
2164	19	AUG Codon (64-73)	P=S
2165	20	AUG Codon (66-80)	P=S
2173	21	AUG Codon (64-79)	P=S

ISIS NO.	SEQ ID NO.	TARGET REGION	MODIFICATION
2302	22	3'-Untranslated (2114-2133)	P=S
2303	23	3'-Untranslated (2039-2058)	P=S
2304	24	3'-Untranslated (1895-1914)	P=S
2305	25	3'-Untranslated (1935-1954)	P=S
2307	26	3'-Untranslated (1976-1995)	P=S
2634	1	AUG-Codon (64-81)	2'-fluoro A,C & U; P=S
2637	15	3'-Untrans(1952-1971)	2'-fluoro A, C & U;
2691	1	AUG Codon (64-81)	P=O, except last 3 bases, P=S
2710	15	3'-Untrans. (1952-1971)	2'-O-methyl; P=O
2711	1	AUG Codon (64-81)	2'-O-methyl; P=O
2973	15	3'-Untrans.(1952-1971)	2'-O-methyl; P=S
2974	1	AUG Codon (64-81)	2'-O-methyl; P=S
3064	27	5'-CAP (32-51)	P=S; G & C added as spacer to 3'
3067	84	5'-CAP (32-51)	P=S
3222	84	5'-CAP (32-51)	2'-O-methyl; P=O
3224	84	5'-CAP (32-51)	2'-O-methyl; P=S
3581	85	3'-Untranslated (1959-1978)	P=S

Inhibition of ICAM-1 expression on the surface of interleukin-1ß-stimulated cells by the oligonucleotides was determined by ELISA assay as described in Example 1. The oligonucleotides were tested in two different cell lines. None of the phosphodiester oligonucleotides inhibited ICAM-1 expression. This is probably due to the rapid degradation of phosphodiester oligonucleotides in cells. Of the five phosphorothioate oligonucleotides, the most active was ISIS 1570, which hybridizes to the AUG translation initiation codon. A 2'-o-methyl phosphorothioate oligonucleotide, ISIS

2974, was approximately threefold less effective than ISIS 1570 in inhibiting ICAM-1 expression in HUVEC and A549 cells. A 2'-fluoro oligonucleotide, ISIS 2634, was also less effective.

Based on the initial data obtained with the five original targets, additional oligonucleotides were designed which would hybridize with the ICAM-1 mRNA. The antisense oligonucleotide (ISIS 3067) which hybridizes to the predicted transcription initiation site (5' cap site) was approximately as active in IL-1ß-stimulated cells as the oligonucleotide that hybridizes to the AUG codon (ISIS 1570), as shown in Figure 8. ISIS 1931 and 1932 hybridize 5' and 3', respectively, to the AUG translation initiation codon. All three oligonucleotides that hybridize to the AUG region inhibit ICAM-1 expression, though ISIS 1932 was slightly less active than ISIS 1570 and ISIS 1931. Oligonucleotides which hybridize to the coding region of ICAM-1 mRNA (ISIS 1933, 1934, 1935, 1574 and 1936) exhibited weak activity. Oligonucleotides that hybridize to the translation termination codon (ISIS 1937 and 1938) exhibited moderate activity.

Surprisingly, the most active antisense oligonucleotide was ISIS 1939, a phosphorothioate oligonucleotide targeted to a sequence in the 3'- untranslated region of ICAM-1 mRNA (see Table 1). Other oligonucleotides having the same sequence were tested, 2'-O-methyl (ISIS 2973) and 2'-fluoro (ISIS 2637); however, they did not exhibit this level of activity. Oligonucleotides targeted to other 3' untranslated sequences (ISIS 1572, 1573 and 1940) were also not as active as ISIS-1939. In fact, ISIS 1940, targeted to the polyadenylation signal, did not inhibit ICAM-1 expression.

Because ISIS 1939 proved unexpectedly to exhibit the greatest antisense activity of the original 16

oligonucleotides tested, other oligonucleotides were designed to hybridize to sequences in the 3'-untranslated region of ICAM-1 mRNA (ISIS 2302, 2303, 2304, 2305, and 2307, as shown in Table 1). ISIS 2307, which hybridizes to a site only five bases 3' to the ISIS 1939 target, was the least active of the series (Figure 8). ISIS 2302, which hybridizes to the ICAM-1 mRNA at a position 143 bases 3' to the ISIS 1939 target, was the most active of the series, with activity comparable to that of ISIS 1939. Examination of the predicted RNA secondary structure of the human ICAM-1 mRNA 3'-untranslated region (according to M. Zuker, *Science* **1989**, 244, 48-52) revealed that both ISIS 1939 and ISIS 2302 hybridize to sequences predicted to be in a stable stem-loop structure. Current dogma suggests that regions of RNA secondary structure should be avoided when designing antisense oligonucleotides. Thus, ISIS 1939 and ISIS 2302 would not have been predicted to inhibit ICAM-1 expression.

The control oligonucleotide ISIS 1821 did inhibit ICAM-1 expression in HUVEC cells with activity comparable to that of ISIS 1934; however, in A549 cells ISIS 1821 was less effective than ISIS 1934. The negative control, ISIS 1821, was found to have a small amount of activity against ICAM expression, probably due in part to its ability to hybridize (12 of 13 base match) to the ICAM-1 mRNA at a position 15 bases 3' to the AUG translation initiation codon.

These studies indicate that the AUG translation initiation codon and specific 3'-untranslated sequences in the ICAM-1 mRNA were the most susceptible to antisense oligonucleotide inhibition of ICAM-1 expression.

In addition to inhibiting ICAM-1 expression in human umbilical vein cells and the human lung carcinoma cells (A549), ISIS 1570, ISIS 1939 and ISIS 2302 were shown to inhibit ICAM-1 expression in the human epidermal carcinoma A431 cells and in primary human keratinocytes (shown in

Figure 9). These data demonstrate that antisense oligonucleotides are capable of inhibiting ICAM-1 expression in several human cell lines. Furthermore, the rank order potency of the oligonucleotides is the same in the four cell lines examined. The fact that ICAM-1 expression could be inhibited in primary human keratinocytes is important because epidermal keratinocytes are an intended target of the antisense nucleotides.

Example 6

Antisense oligonucleotide inhibition of ICAM-1 expression in cells stimulated with other cytokines

Two oligonucleotides, ISIS 1570 and ISIS 1939, were tested for their ability to inhibit TNF-α and IFN-α-induced ICAM-1 expression. Treatment of A549 cells with 1 μM antisense oligonucleotide inhibited IL-1ß, TNF-α and IFN-α-induced ICAM-1 expression in a sequence-specific manner. The antisense oligonucleotides inhibited IL-1ß and TNF-α-induced ICAM-1 expression to a similar extent, while IFN-α-induced ICAM-1 expression was more sensitive to antisense inhibition. The control oligonucleotide, ISIS 1821, did not significantly inhibit IL-1ß- or TNF-α-induced ICAM-1 expression and inhibited IFN-α-induced ICAM-1 expression slightly, as follows:

Antisense Oligonucleotide
(% Control Expression)

Cytokine	ISIS 1570	ISIS 1939	ISIS 1821
3 U/ml IL-1â	56.6 " 2.9	38.1 " 3.2	95 " 6.6
1 ng/ml TNF-á	58.1 " 0.9	37.6 " 4.1	103.5 " 8.2
100 U/ml gamma-IFN	38.9 " 3.0	18.3 " 7.0	83.0 " 3.5

Example 7

Antisense effects are abolished by sense strand controls

The antisense oligonucleotide inhibition of ICAM-1 expression by the oligonucleotides ISIS 1570 and ISIS 1939 could be reversed by hybridization of the oligonucleotides with their respective sense strands. The phosphorothioate sense strand for ISIS 1570 (ISIS 1575), when applied alone, slightly enhanced IL-1ß-induced ICAM-1 expression. Premixing ISIS 1570 with ISIS 1575 at equal molar concentrations, prior to addition to the cells, blocked the effects of ISIS 1570. The complement to ISIS 1939 (ISIS 2115) enhanced ICAM-1 expression by 46% when added to the cells alone. Prehybridization of ISIS 2115 to ISIS 1939 completely blocked the inhibition of ICAM-1 expression by ISIS 1939.

Example 8

Measurement of oligonucleotide Tm (dissociation temperature of oligonucleotide from target)

To determine if the potency of the inhibition of ICAM-1 expression by antisense oligonucleotides was due to their affinity for their target sites, thermodynamic measurements were made for each of the oligonucleotides. The antisense oligonucleotides (synthesized as phosphorothioates) were hybridized to their complementary DNA sequences (synthesized as phosphodiesters). Absorbance vs. temperature profiles were measured at 4 μM each strand oligonucleotide in 100 mM Na+, 10 mM phosphate, 0.1 mM EDTA, pH 7.0. Tm's and free energies of duplex formation were obtained from fits of data to a two-state model with linear sloping baselines (Petersheim, M. and D.H. Turner, *Biochemistry* **1983**, 22, 256-263). Results are averages of at least three experiments.

When the antisense oligonucleotides were hybridized to their complementary DNA sequences (synthesized as

phosphodiesters), all of the antisense oligonucleotides with the exception of ISIS 1940 exhibited a Tm of at least 50°C. All the oligonucleotides should therefore be capable of hybridizing to the target ICAM-1 mRNA if the target sequences were exposed. Surprisingly, the potency of the antisense oligonucleotide did not correlate directly with either Tm or ÄGE$_{37}$. The oligonucleotide with the greatest biological activity, ISIS 1939, exhibited a Tm which was lower than that of the majority of the other oligonucleotides. Thus, hybridization affinity is not sufficient to ensure biological activity.

Example 9

Effect of oligonucleotide length on antisense inhibition of ICAM-1 expression

The effect of oligonucleotide length on antisense activity was tested using truncated versions of ISIS 1570 (ISIS 2165, 2173, 2149, 2163 and 2164) and ISIS 1939 (ISIS 2540, 2544, 2545, 2546, 2547 and 2548). In general, antisense activity decreased as the length of the oligonucleotides decreased. Oligonucleotides 16 bases in length exhibited activity slightly less than 18 base oligonucleotides. Oligonucleotides 14 bases in length exhibited significantly less activity, and oligonucleotides 12 or 10 bases in length exhibited only weak activity. Examination of the relationship between oligonucleotide length and Tm and antisense activity reveals that a sharp transition occurs between 14 and 16 bases in length, while Tm increases linearly with length (Figure 10).

Example 10

Specificity of antisense inhibition of ICAM-1

The specificity of the antisense oligonucleotides ISIS 1570 and ISIS 1939 for ICAM-1 was evaluated by

immunoprecipitation of ^{35}S-labelled proteins. A549 cells were grown to confluence in 25 cm^2 tissue culture flasks and treated with antisense oligonucleotides as described in Example 4. The cells were stimulated with interleukin-1ß for 14 hours, washed with methionine-free DMEM plus 10% dialyzed fetal calf serum, and incubated for 1 hour in methionine-free medium containing 10% dialyzed fetal calf serum, 1 μM oligonucleotide and interleukin-1ß as indicated. ^{35}S-Methionine/cysteine mixture (Tran^{35}S-label, purchased from ICN, Costa Mesa, CA) was added to the cells to an activity of 100 μCi/ml and the cells were incubated an additional 2 hours. Cellular proteins were extracted by incubation with 50 mM Tris-HCl pH 8.0, 150 mM NaCl, 1.0% NP-40, 0.5% deoxycholate and 2 mM EDTA (0.5 ml per well) at 4°C for 30 minutes. The extracts were clarified by centrifugation at 18,000 x g for 20 minutes. The supernatants were preadsorbed with 200 μl protein G-Sepharose beads (Bethesda Research Labs, Bethesda MD) for 2 hours at 4°C, divided equally and incubated with either 5 μg ICAM-1 monoclonal antibody (purchased from AMAC Inc., Westbrook ME) or HLA-A,B antibody (W6/32, produced by murine hybridoma cells obtained from the American Type Culture Collection, Bethesda, MD) for 15 hours at 4°C. Immune complexes were trapped by incubation with 200 μl of a 50% suspension of protein G-Sepharose (v/v) for 2 hours at 4°C, washed 5 times with lysis buffer and resolved on an SDS-polyacrylamide gel. Proteins were detected by autoradiography.

Treatment of A549 cells with 5 units/ml of interleukin-1ß was shown to result in the synthesis of a 95-100 kDa protein migrating as a doublet which was immunoprecipitated with the monoclonal antibody to ICAM-1. The appearance as a doublet is believed to be due to differently glycosylated forms of ICAM-1. Pretreatment of the cells with the antisense oligonucleotide ISIS 1570 at a concentration of 1

μM decreased the synthesis of ICAM-1 by approximately 50%, while 1 μM ISIS 1939 decreased ICAM-1 synthesis to near background. Antisense oligonucleotide ISIS 1940, inactive in the ICAM-1 ELISA assay (Examples 1 and 5) did not significantly reduce ICAM-1 synthesis. None of the antisense oligonucleotides hybridizable with ICAM-1 targets had a demonstrable effect on HLA-A, B synthesis, demonstrating the specificity of the oligonucleotides for ICAM-1. Furthermore, the proteins which nonspecifically precipitated with the ICAM-1 antibody and protein G-Sepharose were not significantly affected by treatment with the antisense oligonucleotides.

Example 11

Screening of additional antisense oligonucleotides for activity against ICAM-1 by cell adhesion assay

Human umbilical vein endothelial (HUVEC) cells were grown and treated with oligonucleotides as in Example 4. Cells were treated with either ISIS 1939, ISIS 1940, or the control oligonucleotide ISIS 1821 for 4 hours, then stimulated with TNF-α for 20 hours. Basal HUVEC minimally bound HL-60 cells, while TNF-stimulated HUVEC bound 19% of the total cells added. Pretreatment of the HUVEC monolayer with 0.3 ìM ISIS 1939 reduced the adherence of HL-60 cells to basal levels, as shown in Figure 11. The control oligonucleotide, ISIS 1821, and ISIS 1940 reduced the percentage of cells adhering from 19% to 9%. These data indicate that antisense oligonucleotides targeting ICAM-1 may specifically decrease adherence of a leukocyte-like cell line (HL-60) to TNF-α-treated HUVEC.

Example 12

ELISA screening of antisense oligonucleotides for activity against ELAM-1 gene expression

Primary human umbilical vein endothelial (HUVEC) cells, passage 2 to 5, were plated in 96-well plates and allowed to reach confluence. Cells were washed three times with Opti-MEM (GIBCO, Grand Island NY). Cells were treated with increasing concentrations of oligonucleotide diluted in Opti-MEM containing 10 μg/ml DOTMA solution (Bethesda Research Labs, Bethesda, MD) for 4 hours at 37°C. The medium was removed and replaced with EGM-UV (Clonetics, San Diego CA) plus oligonucleotide. Tumor necrosis factor α was added to the medium (2.5 ng/ml) and the cells were incubated an additional 4 hours at 37°C.

ELAM-1 expression was determined by ELISA. Cells were gently washed three times with Dulbecco's phosphate-buffered saline (D-PBS) prewarmed to 37°C. Cells were fixed with 95% ethanol at 4°C for 20 minutes, washed three times with D-PBS and blocked with 2% BSA in D-PBS. Cells were incubated with ELAM-1 monoclonal antibody BBA-1 (R&D Systems, Minneapolis MN) diluted to 0.5 μg/ml in D-PBS containing 2% BSA for 1 hour at 37°C. Cells were washed three times with D-PBS and the bound ELAM-1 antibody detected with biotinylated goat anti-mouse secondary antibody followed by ß-galactosidase-conjugated streptavidin as described in Example 1.

The activity of antisense phosphorothioate oligonucleotides which target 11 different regions on the ELAM-1 cDNA and two oligonucleotides which target ICAM-1 (as controls) was determined using the ELAM-1 ELISA. The oligonucleotide and targets are shown in Table 2.

Table 2

ANTISENSE OLIGONUCLEOTIDES WHICH TARGET HUMAN ELAM-1

ISIS NO.	SEQ ID NO.	TARGET REGION	MODIFICATION
1926	28	AUG Codon (143-164)	P=S
2670	29	3'-Untranslated (3718-3737)	P=S
2673	30	3'-Untranslated (2657-2677)	P=S

ISIS NO.	SEQ ID NO.	TARGET REGION	MODIFICATION
2674	31	3'-Untranslated (2617-2637)	P=S
2678	32	3'-Untranslated (3558-3577)	P=S
2679	33	5'-Untranslated (41-60)	P=S
2680	34	3'-Untranslated (3715-3729)	P=S
2683	35	AUG Codon (143-163)	P=S
2686	36	AUG Codon (149-169)	P=S
2687	37	5'-Untranslated (18-37)	P=S
2693	38	3'-Untranslated (2760-2788)	P=S
2694	39	3'-Untranslated (2934-2954)	P=S

In contrast to what was observed with antisense oligonucleotides targeted to ICAM-1 (Example 5), the most potent oligonucleotide modulator of ELAM-1 activity (ISIS 2679) was hybridizable with specific sequences in the 5'-untranslated region of ELAM-1. ISIS 2687, an oligonucleotide which hybridized to sequences ending three bases upstream of the ISIS 2679 target, did not show significant activity (Figure 12). Therefore, ISIS 2679 hybridizes to a unique site on the ELAM-1 mRNA, which is uniquely sensitive to inhibition with antisense oligonucleotides. The sensitivity of this site to inhibition with antisense oligonucleotides was not predictable based upon RNA secondary structure predictions or information in the literature.

Example 13

ELISA screening of additional antisense oligonucleotides for activity against ELAM-1 gene expression

Inhibition of ELAM-1 expression by eighteen antisense phosphorothioate oligonucleotides was determined using the ELISA assay as described in Example 12. The target sites of these oligonucleotides on the ELAM-1 mRNA are shown in Figure 13. The sequence and activity of each oligonucleotide against ELAM-1 are shown in Table 3. The oligonucleotides indicated by an asterisk (*) have IC50's of approximately 50 nM or below and are preferred. IC50 indicates the dosage of oligonucleotide, which results in 50% inhibition of ELAM-1 expression.

TABLE 3

INHIBITION OF HUMAN ELAM-1 EXPRESSION BY ANTISENSE OLIGONUCLEOTIDES

ELAM-1 expression is given as % of control

ISIS#	SEQ ID NO:	POSITION	SEQUENCE	VCAM-1 EXPRESSION	
				30 nM oligo	50 nM oligo
*4764	52	5'-UTR 1-19	GAAGTCAGCCAAGAACAGCT	70.2	50.2
2687	37	5'-UTR 17-36	TATAGGAGTTTTGATGTGAA	91.1	73.8
*2679	33	5'-UTR 40-59	CTGCTGCCTCTGTCTCAGGT	6.4	6.0
*4759	53	5'-UTR 64-83	ACAGGATCTCTCAGGTGGGT	30.0	20.2
*2683	35	AUG 143-163	AATCATGACTTCAAGAGTTCT	47.9	48.5
*2686	36	AUG 148-168	TGAAGCAATCATGACTTCAAG	51.1	46.9
*4756	54	I/E 177-196	CCAAAGTGAGAGCTGAGAGA	53.9	35.7
4732	55	Coding 1936-1955	CTGATTCAAGGCTTTGGCAG	68.5	55.3
*4730	56	I/E 3'UTR 2006-2025	TCCCCAGATGCACCTGTTT	14.1	2.3
*4729	57	3'-UTR 2063-2082	GGGCCAGAGACCCGAGGAGA	49.4	46.3
*2674	31	3'-UTR 2617-2637	CACAATCCTTAAGAACTCTTT	33.5	28.1
2673	30	3'-UTR 2656-2676	GTATGGAAGATTATAATATAT	58.9	53.8

ISIS#	SEQ ID NO:	POSITION	SEQUENCE	VCAM-1 EXPRESSION	
				30 nM oligo	50 nM oligo
2694	39	3'-UTR 2933-2953	GACAATATACAAACCTTCCAT	72.0	64.6
*4719	58	3'-UTR 2993-3012	ACGTTTGGCCTCATGGAAGT	36.8	34.7
4720	59	3'-UTR 3093-3112	GGAATGCAAAGCACATCCAT	63.5	70.6
*2678	32	3'-UTR 3557-3576	ACCTCTGCTGTTCTGATCCT	24.9	15.3
2670	29	3'-UTR 3717-3736	ACCACACTGGTATTTCACAC	72.2	67.2

I/E indicates Intron/Exon junction

Oligonucleotides with IC50's of approximately 50 nM or below are indicated by an asterisk (*).

An additional oligonucleotide targeted to the 3'-untranslated region (ISIS 4728) did not inhibit ELAM expression.

Example 14

ELISA screening of antisense oligonucleotides for activity against VCAM-1 gene expression

Inhibition of VCAM-1 expression by fifteen antisense phosphorothioate oligonucleotides was determined using the ELISA assay approximately as described in Example 12, except that cells were stimulated with TNF-á for 16 hours and VCAM-1 expression was detected by a VCAM-1 specific monoclonal antibody (R & D Systems, Minneapolis, MN) used at 0.5 μg/ml. The target sites of these oligonucleotides on the VCAM-1 mRNA are shown in Figure 14. The sequence and activity of each oligonucleotide against VCAM-1 are shown in Table 4. The oligonucleotides indicated by an asterisk (*) have IC50's of approximately 50 nM or below and are preferred. IC50 indicates the dosage of oligonucleotide which results in 50% inhibition of VCAM-1 expression.

Table 4

INHIBITION OF HUMAN VCAM-1 EXPRESSION BY ANTISENSE OLIGONUCLEOTIDES

VCAM-1 expression is given as % of control

ISIS#	SEQ ID NO:	POSITION	SEQUENCE	VCAM-1 EXPRESSION	
				30 nM oligo	50 nM oligo
*5884	60	5'-UTR 1-19	CGATGCAGATACCGCGGAGT	79.2	37.2
3791	61	5'-UTR 38-58	CCTGGGAGGGTATTCAGCT	92.6	58.0
5862	62	5'-UTR 48-68	CCTGTGTGTGCCTGGGAGGG	115.0	3.5
*3792	63	AUG 110-129	GGCATTTTAAGTTGCTGTCG	68.7	33.7
5863	64	CODING 745-764	CAGCCTGCCTTACTGTGGGC	95.8	66.7
*5874	65	CODING 1032-1052	CTTGAACAATTAATTCCACCT	66.5	35.3
5885	66	E/I 1633-1649+intron	TTACCATTGACATAAAGTGTT	84.4	52.4
*5876	67	CODING 2038-2057	CTGTGTCTCCTGTCTCCGCT	43.5	26.6
*5875	68	CODING 2183-2203	GTCTTTGTTGTTTTCTCTTCC	59.2	34.8
3794	69	TERMIN. 2344-2362	TGAACATATCAAGCATTAGC	75.3	52.6
*3800	70	3'-UTR 2620-2639	GCAATCTTGCTATGGCATAA	64.4	47.7
*3805	71	3'-UTR 2826-2845	CCCGGCATCTTTACAAAACC	7.7	44.9
*3801	50	3'-UTR 2872-2892	AACCCAGTGCTCCCTTTGCT	36.5	21.3
*5847	72	3'-UTR 2957-2976	AACATCTCCGTACCATGCCA	51.8	24.6
*3804	51	3'-UTR 3005-3024	GGCCACATTGGGAAAGTTGC	55.1	29.3

E/I indicates exon/intron junction

Oligonucleotides with IC50's of approximately 50 nM or below are indicated by an asterisk (*).

Example 15

ICAM-1 expression in C8161 human melanoma cells

Human melanoma cell line C8161 (a gift of Dr. Dan Welch, Hershey Medical Center) was derived from an abdominal wall metastasis from a patient with recurrent malignant melanoma. These cells form multiple metastases in lung, subcutis, spleen, liver and regional lymph nodes after subcutaneous, intradermal and intravenous injection into athymic nude mice. Cells were grown in DMA-F12 medium containing 10% fetal calf serum and were passaged using 2 mM EDTA.

Exposure of C8161 cells to TNF-α resulted in a six-fold increase in cell surface expression of ICAM-1 and an increase in ICAM-1 mRNA levels in these cells. ICAM-1 expression on the cell surface was measured by ELISA. Cells were treated with increasing concentrations of antisense oligonucleotides in the presence of 15 μg/ml Lipofectin for 4 hours at 37°C. ICAM-1 expression was induced by incubation with 5 ng/ml TNF-α for 16 hours. Cells were washed 3x in DPBS and fixed for 20 minutes in 2% formaldehyde. Cells were washed in DPBS, blocked with 2% BSA for 1 hour at 37°C and incubated with ICAM-1 monoclonal antibody 84H10 (AMAC, Inc., Westbrook, ME). Detection of bound antibody was determined by incubation with a biotinylated goat anti-mouse IgG followed by incubation with ß-galactosidase-conjugated streptavidin and developed with chlorophenol red-ß-D-galactopyranoside and quantified by absorbance at 575 nm. ICAM-1 mRNA levels were measured by Northern blot analysis.

Example 16

Oligonucleotide inhibition of ICAM-1 expression in C8161 human melanoma cells

As shown in Figure 15, antisense oligonucleotides ICAM 1570 (SEQ ID NO: 1), ISIS 1939 (SEQ ID NO: 15) and ISIS 2302 (SEQ ID NO: 22) targeted to ICAM-1 decreased cell surface expression of ICAM-1 (detected by ELISA as in Example 16). ISIS 1822, a negative control oligonucleotide complementary to 5-lipoxygenase, did not affect ICAM-1 expression. The data were expressed as percentage of control activity, calculated as follows: (ICAM-1 expression for oligonucleotide-treated, cytokine-induced cells)-(basal ICAM-1 expression)/(ICAM-1 cytokine-induced expression)-(basal ICAM-1 expression) x 100.

ISIS 1939 (SEQ ID NO: 15) and ISIS 2302 (SEQ ID NO: 22) markedly reduced ICAM-1 mRNA levels (detected by Northern blot analysis), but ISIS 1570 (SEQ ID NO: 1) decreased ICAM-1 mRNA levels only slightly.

Example 17

Experimental metastasis assay

To evaluate the role of ICAM-1 in metastasis, experimental metastasis assays were performed by injecting 1 x 10^5 C8161 cells into the lateral tail vein of athymic nude mice. Treatment of C8161 cells with the cytokine TNF-α and interferon α has previously been shown to result in an increased number of lung metastases when cells were injected into nude mice [Miller, D.E. and Welch, D.R., *Proc. Am. Assoc. Cancer Res.* **1990**, 13, 353].

After 4 weeks, mice were sacrificed, organs were fixed in Bouin's fixative and metastatic lesions on lungs were scored with the aid of a dissecting microscope. Four-week-old female athymic nude mice (Harlan Sprague Dawley) were used. Animals were maintained under the guidelines of the

NIH. Groups of 4-8 mice each were tested in experimental metastasis assays.

Example 18

Antisense oligonucleotides ISIS 1570 and ISIS 2302 decrease metastatic potential of C8161 cells

Treatment of C8161 cells with antisense oligonucleotides ISIS 1570 and ISIS 2302, complementary to ICAM-1, was performed in the presence of the cationic lipid, Lipofectin (Gibco/BRL, Gaithersburg, MD). Antisense oligonucleotides were synthesized as described in Example 3. Cells were seeded in 60 mm tissue culture dishes at 10^6 cells/ml and incubated at 37°C for 3 days, washed with OPTI-MEM (Gibco/BRL) 3 times and 100 μl of OPTI-MEM medium was added to each well. 0.5 μM oligonucleotide and 15 μg/ml lipofectin were mixed at room temperature for 15 minutes. 25 μl of the oligonucleotide-lipofectin mixture was added to the appropriate dishes and incubated at 37°C for 4 hours. The oligonucleotide-lipofectin mixture was removed and replaced with DME-F12 medium containing 10% fetal calf serum. After 4 hours, 500 U/ml TNF-α was added to the appropriate wells and incubated for 18 hours at which time cells were removed from the plates, counted and injected into athymic nude mice.

Treatment of C8161 cells with ISIS 1570 (SEQ ID NO: 1) or ISIS 2302 (SEQ ID NO: 22) decreased the metastatic potential of these cells, and eliminated the enhanced metastatic ability of C8161 which resulted from TNF-á treatment. Data are shown in Table 5.

Table 5

EFFECT OF ANTISENSE OLIGONUCLEOTIDES TO ICAM-1 ON EXPERIMENTAL METASTASIS OF HUMAN MELANOMA CELL LINE C8161

Treatment	No. Lung Metastases per Mouse **(Mean ± S.E.M.)**
Lipofectin only	64 ± 13
Lipofectin + TNF-á	81 ± 8
ISIS-1570 + Lipofectin	38 ± 15
ISIS-2302 + Lipofectin	23 ± 6
ISIS-1570 + Lipofectin + TNF-á	49 ± 6
ISIS-2302 + Lipofectin + TNF-á	31 ± 8

Example 19

Murine models for testing antisense oligonucleotides against ICAM-1

Many conditions which are believed to be mediated by intercellular adhesion molecules are not amenable to study in humans. For example, allograft rejection is a condition which is likely to be ameliorated by interference with ICAM-1 expression, but clearly this must be evaluated in animals rather than human transplant patients. Another such example is inflammatory bowel disease, and yet another is neutrophil migration (infiltration). These conditions can be tested in animal models, however, such as the mouse models used here. Oligonucleotide sequences for inhibiting ICAM-1 expression in murine cells were identified. Murine ICAM-1 has approximately 50% homology with the human ICAM-1 sequence; a series of oligonucleotides which target the mouse ICAM-1 mRNA sequence were designed and synthesized, using information gained from evaluation of oligonucleotides

targeted to human ICAM-1. These oligonucleotides were screened for activity using an immunoprecipitation assay.

Murine DCEK-ICAM-1 cells (a gift from Dr. Adrienne Brian, University of California at San Diego) were treated with 1 ìM of oligonucleotide in the presence of 20 μg/ml DOTMA/DOPE solution for 4 hours at 37°C. The medium was replaced with methionine-free medium plus 10% dialyzed fetal calf serum and 1 μM antisense oligonucleotide. The cells were incubated for 1 hour in methionine-free medium, then 100 μCi/ml ^{35}S-labeled methionine/cysteine mixture was added to the cells. Cells were incubated an additional 2 hours, washed 4 times with PBS, and extracted with buffer containing 20 mM Tris, pH 7.2, 20 mM KCl, 5 mM EDTA, 1% Triton X-100, 0.1 mM leupeptin, 10 μg/ml aprotinin, and 1 mM PMSF. ICAM-1 was immunoprecipitated from the extracts by incubating with a murine-specific ICAM-1 antibody (YN1/1.7.4) followed by protein G-sepharose. The immunoprecipitates were analyzed by SDS-PAGE and autoradiographed. Phosphorothioate oligonucleotides ISIS 3066 and 3069, which target the AUG codon of mouse ICAM-1, inhibited ICAM-1 synthesis by 48% and 63%, respectively, while oligonucleotides ISIS 3065 and ISIS 3082, which target sequences in the 3'-untranslated region of murine ICAM-1 mRNA inhibited ICAM-1 synthesis by 47% and 97%, respectively. The most active antisense oligonucleotide against mouse ICAM-1 was targeted to the 3'-untranslated region. ISIS 3082 was evaluated further based on these results; this 20-mer phosphorothioate oligonucleotide comprises the sequence (5' to 3') TGC ATC CCC CAG GCC ACC AT (SEQ ID NO: 83).

Example 20

Antisense oligonucleotides to ICAM-1 reduce inflammatory bowel disease in murine model system

A mouse model for inflammatory bowel disease (IBD) has recently been developed. Okayasu et al., *Gastroenterology* **1990**, 98, 694-702. Administration of dextran sulfate to mice induces colitis that mimics human IBD in almost every detail. Dextran sulfate-induced IBD and human IBD have subsequently been closely compared at the histological level and the mouse model has been found to be an extremely reproducible and reliable model. It is used here to test the effect of ISIS 3082, a 20-base phosphorothioate antisense oligonucleotide which is complementary to the 3' untranslated region of the murine ICAM-1.

Female Swiss Webster mice (8 weeks of age) weighing approximately 25 to 30 grams are kept under standard conditions. Mice are allowed to acclimate for at least 5 days before initiation of experimental procedures. Mice are given 5% dextran sulfate sodium in their drinking water (available ad libitum) for 5 days. Concomitantly, ISIS 3082 oligonucleotide in pharmaceutical carrier, carrier alone (negative control) or TGF-ß (known to protect against dextran sulfate-mediated colitis in mice) is administered. ISIS 3082 was given as daily subcutaneous injection of 1 mg/kg or 10 mg/kg for 5 days. TGF-ß was given as 1 μg/mouse intracolonically. At 1 mg/kg, the oligonucleotide was as effective as TGF-α in protecting against dextran-sulfate-induced colitis.

Mice were sacrificed on day 6 and colons were subjected to histopathologic evaluation. Until sacrifice, disease activity was monitored by observing mice for weight changes and by observing stools for evidence of colitis. Mice were weighed daily. Stools were observed daily for changes in

consistency and for presence of occult or gross bleeding. A scoring system was used to develop a disease activity index by which weight loss, stool consistency and presence of bleeding were graded on a scale of 0 to 3 (0 being normal and 3 being most severely affected) and an index was calculated. Drug-induced changes in the disease activity index were analyzed statistically. The disease activity index has been shown to correlate extremely well with IBD in general. Results are shown in Figure 16. At 1 mg/kg, the oligonucleotide reduced the disease index by 40%.

Example 21

Antisense oligonucleotide to ICAM-1 increases survival in murine heterotopic heart transplant model

To determine the therapeutic effects of ICAM-1 antisense oligonucleotide in preventing allograft rejection the murine ICAM-1 specific oligonucleotide ISIS 3082 was tested for activity in a murine vascularized heterotopic heart transplant model. Hearts from Balb/c mice were transplanted into the abdominal cavity of C3H mice as primary vascularized grafts essentially as described by Isobe et al., *Circulation* **1991**, 84, 1246-1255. Oligonucleotides were administered by continuous intravenous administration via a 7-day Alzet pump. The mean survival time for untreated mice was 9.2 ± 0.8 days (8, 9, 9, 9, 10, 10 days). Treatment of the mice for 7 days with 5 mg/kg ISIS 3082 increased the mean survival time to 14.3 ± 4.6 days (11, 12, 13, 21 days).

Example 22

Antisense oligonucleotide to ICAM-1 decreases leukocyte migration

Leukocyte infiltration of tissues and organs is a major aspect of the inflammatory process and contributes to tissue

damage resulting from inflammation. The effect of ISIS 3082 on leukocyte migration was examined using a mouse model in which carrageenan-soaked sponges were implanted subcutaneously. Carrageenan stimulates leukocyte migration and edema. Effect of oligonucleotide on leukocyte migration in inflammatory exudates is evaluated by quantitation of leukocytes infiltrating the implanted sponges. Following a four hour fast, 40 mice were assigned randomly to eight groups each containing five mice. Each mouse was anesthetized with Metofane and a polyester sponge impregnated with 1 ml of a 20 mg/ml solution of carrageenan was implanted subcutaneously. Saline was administered intravenously to Group 1 at 10 ml/kg four hours prior to sponge implantation and this served as the vehicle control. Indomethacin (positive control) was administered orally at 3 mg/kg at a volume of 20 ml/kg to Group 2 immediately following surgery, again 6-8 hours later and again at 21 hours post-implantation. ISIS 3082 was administered intravenously at 5 mg/kg to Group 3 four hours prior to sponge implantation. ISIS 3082 was administered intravenously at 5 mg/kg to Group 4 immediately following sponge implantation. ISIS 3082 was administered intravenously at 5 mg/kg to Groups 5, 6, 7 and 8 at 2, 4, 8 and 18 hours following sponge implantation, respectively. Twenty-four hours after implantation, sponges were removed, immersed in EDTA and saline (5 ml) and squeezed dry. Total numbers of leukocytes in sponge exudate mixtures were determined.

The oral administration of indomethacin at 3 mg/kg produced a 79% reduction in mean leukocyte count when compared to the vehicle control group.

A 42% reduction in mean leukocyte count was observed following the administration of ISIS 3082 at 5 mg/kg four hours prior to sponge implantation (Group 3). A 47%

reduction in mean leukocyte count was observed following the administration of ISIS 3082 at 5 mg/kg immediately following sponge implantation (Group 4). All animals appeared normal throughout the course of study.

Example 23

Compatibility of antisense oligonucleotide with corneal donor storage media and determination of toxicity

The following studies were performed to determine whether antisense oligonucleotides were toxic to normal ocular tissues. A 20-mer antisense phosphorothioate oligonucleotide (APO) in three different concentrations (40, 200 and 400 μg/ml) was stored in OPTISOL™ corneal donor storage media (Bausch & Lomb) for a total of 30 days. At day 0, 2, 8 and 30 of incubation, aliquots from each concentration were removed, 2 ml samples were placed in freezer-safe tubes and frozen at -100°C for storage. Samples were thawed and analyzed by capillary gel electrophoresis (CGE). Another 2ml aliquot was obtained for each day for analysis of degradability using by spectrophotometry at 260 nm. The dose response curve in water was linear from 5-200 μg/ml concentrations. The samples containing OPTISOL™ were diluted 1:10 to decrease interference in the spectrophotometer.

No degradation or breakdown components of APO over the 30-day storage period was detected by CGE; however, degradation was observed when analysis was performed by spectrophotometry as indicated as decreased absorbance. Absorbance decreased by 39% after 8 days in the 400 μg/ml samples, 37% in the 200 g/ml samples and 60% in the 40 μg/ml samples on average. Thus, at the concentrations studied, the APO is stable in OPTISOL™ and does not appear to break down as determined by CGE.

Human donor corneas that were unsuitable for transplant were incubated with 3 different concentrations of APO in OPTISOL™ and evaluated after 1, 3 and 8 days using the same criteria applied to corneas for transplant. Corneas were fixed for histologic evaluation by light and electron microscopy. Although all corneas deteriorated over time, low concentrations of APO did not significantly affect either epithelial or endothelial cellular integrity, deturgescence or tissue viability. Thee results for the 1 and 8 day incubations are summarized in Table 6.

Table 6

CORNEAL CHANGES OBSERVED AFTER STORAGE FOR 24 HOURS OR 8 DAYS BY LIGHT MICROSCOPY ANALYSIS

	Edema	Epithelial defect	Inflammation	Absence of polarity
APO (24 h)	1/7	2/7	2/7	3/7
Control(24 h)	0/2	1/2	0/2	0/2
APO (8 days)	3/9	1/9	0/9	7/9
Control(8 days)	1/11	2/11	3/11	9/11

Rabbits were treated with topical doses (200 and 400 g/ml) of APO for 10 days four times per day. A different concentration was used in each of the two groups. The ocular surface was assessed by clinical examination using the MacDonald-Shadduck toxicology scale. No local toxicity was reported on the MacDonald-Shadduck scale or by light microscopy. The results are shown in Table 7.

Table 7

MACDONALD-SHADDUCK OCULAR IRRITATION SCORES

	Control[1]	APO (40 μg/ml)	APO (400 μg/ml)
Conjunctiva:			
Injection	Normal	Minor[2]	Minor
Chemosis/Swelling	Normal	Minor[3]	Minor
Discharge	None	Minimal	Minimal
Light reflex	Normal	Normal	Slightly sluggish (day 4-8)
Cornea:			
Loss of transparency	None	Minimal (d. 6-7)[4]	Minimal (d. 2-8)
Stromal opacity	None	Minimal (d. 7-8)[5]	Moderate (d. 2-8)[5]
Vascularization	None	None	Minimal[6]
Staining	None	None	None

[1]Vehicle-treated control

[2]Less than 0.5 on a scale of 3.0=minor flushing of palpebral conjunctiva with some perilimbal injection

[3]Less than 0.5 on a scale of 4.0=some swelling without eversion of the lids

[4]Less than 0.5 on a scale of 4.0=some loss of transparency in anterior half of stroma on days 7-8

[5]Minimal>0.5 on a scale of 4.0=>10% area of stromal cloudiness

[6]Moderate 1.0 on a scale of 4.0=<25% area of stromal cloudiness

In addition, serum and aqueous humor were withdrawn and analyzed for the presence of APO to evaluate the ability to penetrate through the corneal tissues. The amount of APO in the serum was less than the limit of detection of the assay method. Significant amounts of APO were found to have penetrated into the aqueous humor, demonstrating the ability

of the APO to penetrate through the cornea. After 10 days, the cornea and conjunctiva were studied by light and electron microscopy. By specular microscopy, there were no significant differences between corneas incubated in OPTISOL™ alone or with APO. Light microscopy demonstrated that epithelial polarity and thickness was unaffected by 200 μg/ml and was minimally affected at 400 μg/ml. Scanning electron microscopy (SEM) indicated that storage of corneas up to 8 days did not further increase the time related corneal endothelial degradation.

The experiments described above show that the antisense phosphorothioate oligonucleotides are compatible with corneal storage media, are not toxic to human corneas stored in corneal storage media and are not damaging to normal eye tissue when applied topically.

Example 24

Effect of ISIS 2302 on corneal integrity and tissue viability

Eleven human corneal donor buttons were stored in OPTISOL™ for 8 days and used as the control group. Additional corneal buttons were used for the experimental group and were stored in OPTISOL™ with either 200 μg/ml ISIS 2302 (n=10) or 400 μg/ml ISIS 2302 (n=8). Endothelial cell density was evaluated by specular microscopy. After 8 days, all corneas were prepared for SEM and photographs were taken of endothelial and epithelial surfaces.

Analysis by specular microscopy found that after 2 or 8 days of storage, there was no difference in endothelial cell density among the 3 groups. Both surfaces of the control and experimental groups were analyzed for cellular degradation as well as similarities and differences in their appearance. SEM revealed heavy exfoliation of the epithelial surface of the control group and moderate to

heavy pitting and enucleation of the endothelial surface. The corneal buttons exposed to 200 or 400 μg/ml ISIS 2302 were similar in appearance to corneas in the control group. Severe pitting and hollowing of the endothelial surface and shedding of the epithelial surface seem to be consistent in both the control and experimental groups.

Although there were no obvious differences between the experimental and control groups, it should be noted that all corneal buttons were 1-2 days out of the orbit before experimentation began. Furthermore, after eight days in storage, sloughing and loss of the surface cells are to be expected. Thus, ISIS 2302 is not markedly toxic to stored human corneas.

Example 25

Effects of ICAM-1 antisense oligonucleotides (ISIS 9125 and 2105) on allograft rejection

The following study was preformed to determine whether pretreating corneal allografts with the rat ICAM-1 antisense oligonucleotides ISIS 9125 (5'-AGGGCCACTGCTCGTCCACA-3', all 2'-deoxyphosphorothioate) (SEQ ID NO: 86) and ISIS 2105 inhibited corneal allograft rejection. Rejection was induced in rat corneas by removing the corneas from anesthetized donor ACI rats and transplanting them to anesthetized recipient Lewis rats. In this model of corneal transplant rejection, Lewis rat recipients normally produce a rejection reaction within 6-8 days. The cornea transplants were performed after pretreatment of the donor ACI corneas with either ISIS 9125 or with vehicle (Optisol™) alone. Under surgical anesthesia (ketamine 80 mg/kg, acepromazine 12 mg/kg), a 3 mm section of cornea was removed from one eye of the recipient rat, without damaging internal eye structures. Using the operating microscope, the donor corneal allograft was fitted over the recipient's corneal

opening, and 8 to 12 sutures placed aseptically to secure the corneal allograft. Once sutures were in place, the anterior chamber was re-inflated using sterile saline, and tobramycin antibiotic ointment with dexamethasone was applied to the surgical site. The animals were allowed to recover and respiration and behavior were monitored. Some donor corneas were incubated in OPTISOL™ containing 400 μg/ml ISIS 9125 for 24 hours before transplantation.

Rats were examined post-op by slit lamp and rejection was based on the MacDonald-Shadduck scale modified for corneal graft rejection. Rejection criteria included corneal opacity, neovascularization, keratic precipitates and conjunctival inflammation. Following rejection, corneas were harvested for examination under light microscopy (H&E) and SEM. Some corneas were harvested on post-op day 3 for histologic examination. Confocal microscopy was used to document epithelial and endothelial changes *in vivo*.

Corneas transplanted immediately after removal from donor rats rejected an average of 5.94 days (range 4-8 days), while those treated with topical steroid lasted an average of 8.40 days (range 6-11 days). The group whose corneas were incubated in OPTISOL™ for 24 hours rejected an average of 4.80 days (range 3-7 days). Those whose corneas were incubated in OPTISOL™ plus ISIS 9125 for 24 hours rejected an average of 6.33 days (range 6-10 days). By day 3 post-surgery, the ISIS 9125 plus OPTISOL™ group was graded 50% better than the OPTISOL™ alone group for cornea opacity and neovascularization; however, the ISIS 9125 group had more corneal edema than the OPTISOL™ alone group.

A similar procedure was used with ISIS 2105 as the antisense oligonucleotide. The percent of allograft recipients showing no signs of rejection 3 days post-op in category is shown in Table 8.

Table 8

PERCENT OF ALLOGRAFT RECIPIENTS SHOWING NO SIGNS OF REJECTION 3 DAYS POST-OP IN CATEGORY

Examination item	No pre/post treatment	Post-op steroids alone	24 hr pre-op Optisol storage alone	24 hr pre-op ISIS/Optisol storage
Conjunctival congestion	100	100	100	100
Conjunctival discharge	88	100	100	100
Iris	100	100	100	100
Graft opacity	44	67	50	80
Graft edema	25	33	0	40
Graft neovascularization	0	67	50	100
Graft staining	94	83	100	100
Keratic precips	100	100	100	100

The data show the ability of ISIS 9125 and 2105 to inhibit corneal rejection. Data with steroids, which increased days to rejection by 30%, confirms the validity of the transplant model. ISIS 9125 increased days to rejection by 25% over the 24 hour OPTISOL™ incubation control group. More subtle signs of inflammation were documented *in vivo* by confocal microscopy than could be detected by slit lamp. Although the allograft experiments were conducted with ISIS 9125, the use of other antisense oligonucleotides targeted to cellular adhesion molecules, particularly ICAM-1, VCAM-1 and ELAM-1, for inhibiting corneal allograft rejection is also within the scope of the present invention. The ability of any antisense oligonucleotide targeted to a cell adhesion

molecule to inhibit corneal allograft rejection can be easily determined without undue experimentation by using the protocols described in the present application.